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ENGINEERING SCIENCE BEFORE, DURING AND AFTER THE WAR[1]

THREE years of anxiety and stress have passed since the last meeting of the British Association. The weight of the struggle which pressed heavily upon us at the time of the Newcastle meeting in 1916 had increased so much in intensity by the spring of 1917 that the council, after consultation with the local committee at Bournemouth, finally decided to cancel the summer meeting of that year. This was the first time in the history of the association that an annual meeting was not held.

We all rejoice to feel that the terrible ordeal through which the whole empire has been passing has now reached its final phases, and that during the period of reorganization, social and industrial, it is possible to resume the annual meetings of the association under happier conditions. We have gladly and with much appreciation accepted the renewed invitation of our friends and colleagues at Bournemouth.

We are gathered together at a time when, after a great upheaval, the elemental conditions of organization of the world are still in flux, and we have to consider how to influence and mould the recrystallization of these elements into the best forms and most economic rearrangements for the benefit of civilization. That the British Association is capable of exerting a great influence in guiding the nation towards advancement in the sciences and arts in the most general sense there can be no ques-

[1] Address of the president of the British Association for the Advancement of Science, Bournemouth, 1919.

tion, and of this we may be assured by a study of its proceedings in conjunction with the history of contemporary progress. Although the British Association can not claim any paramount prerogative in this good work, yet it can certainly claim to provide a free arena for discussion where in the past new theories in science, new propositions for beneficial change, new suggestions for casting aside fetters to the advancement in science, art, and economics have first seen the light of publication and discussion.

For more than half a century it has pleaded strongly for the advancement of science and its application to the arts. In the yearly volume for 1855 will be found a report in which it is stated that:

> The objects for which the association was established have been carried out in three ways: First, by requisitioning and printing reports on the present state of different branches of science; secondly, by granting sums of money to small committees or individuals, to enable them to carry on new researches; and thirdly, by recommending the government to undertake expeditions of discovery, or to make grants of money for certain and national purposes, which were beyond the means of the association.

As a matter of fact it has, since its commencement, paid out of its own funds upwards of £80,000 in grants of this kind.

DEVELOPMENTS PRIOR TO THE WAR

It is twenty-nine years since an engineer, Sir Frederick Bramwell, occupied this chair and discoursed so charmingly on the great importance of the next-to-nothing, the importance of looking after little things which, in engineering, as in other walks of life, are often too lightly considered.

The advances in engineering during the last twenty years are too many and complex to allow of their description, however short, being included in one address, and, following the example of some of my predecessors in this chair, I shall refer only to some of the most important features of this wide subject. I feel that I can not do better than begin by quoting from a speech made recently by Lord Inchcape, when speaking on the question of the nationalization of coal: "It is no exaggeration to say that coal has been the maker of modern Britain, and that those who discovered and developed the methods of working it have done more to determine the bent of British activities and the form of British society than all the Parliaments of the past hundred and twenty years."

James Watt.—No excuse is necessary for entering upon this theme, because this year marks the hundredth anniversary of the death of James Watt, and in reviewing the past it appears that England has gained her present proud position by her early enterprise and by the success of the Watt steam-engine which enabled her to become the first country to develop her resources in coal, and led to the establishment of her great manufactures and her immense mercantile marine.

The laws of steam which James Watt discovered are simply these: That the latent heat is nearly constant for different pressures within the ranges used in steam-engines, and that, consequently, the greater the steam pressure and the greater the range of expansion, the greater will be the work obtained from a given amount of steam. Secondly, as may now seem to us obvious, that steam from its expansive force will rush into a vacuum. Having regard to the state of knowledge at the time, his conclusions appear to have been the result of close and patient reasoning by a mind endowed with extraordinary powers of insight into physical questions, and with the faculty of drawing sound practical conclusions from numerous experiments de-

vised to throw light on the subject under investigation. His resource, courage and devotion were extraordinary.

In commencing his investigations on the steam-engine he soon discovered that there was a tremendous loss in the Newcomen engine, which he thought might be remedied. This was the loss caused by condensation of the steam on the cold metal walls of the cylinder. He first commenced by lining the walls with wood, a material of low thermal conductivity. Though this improved matters, he was not satisfied; his intuition probably told him that there should be some better solution of the problem, and doubtless he made many experiments before he realized that the true solution lay in a condenser separate from the cylinder of the engine. It is easy after discovery to say, "How obvious and how simple," but many of us here know how difficult is any step of advance when shrouded by unknown surroundings, and we can well appreciate the courage and the amount of investigation necessary before James Watt thought himself justified in trying the separate condenser. But to us now, and to the youngest student who knows the laws of steam as formulated by Carnot, Joule and Kelvin, the separate condenser is the obvious means of constructing an economical condensing engine.

Watts experiments led him to a clear view of the great importance of securing as much expansion as possible in his engines. The materials and appliances for boiler and machine construction were at that time so undeveloped that steam pressures were practically limited to a few pounds above atmospheric pressure. The cylinders and pistons of his engines were not constructed with the facility and accuracy to which we are now accustomed, and chiefly for these reasons expansion ratios of from twofold to threefold were the usual practise. Watt had given to the world an engine which consumed from five to seven pounds of coal per horse-power hour, or one-quarter of the fuel previously used by any engine. With this consumption of fuel its field under the conditions prevailing at the time was practically unlimited. What need was there, therefore, for commercial reasons, to endeavor still further to improve the engine at the risk of encountering fresh difficulties and greater commercial embarrassments? The course was rather for him and his partners to devote all their energy to extend the adoption of the engine as it stood, and this they did, and to the Watt engine, consuming from five to seven pounds of coal per horse-power, mankind owes the greatest permanent advances in material welfare recorded in history.

With secondary modifications, it was the prime mover in most general use for eighty years, *i. e.* until the middle of last century. It remained for others to carry the expansion of steam still further in the compound, triple, and, lastly, in the quadruple expansion engine, which is the most economical reciprocating engine of to-day.

Watt had considered the practicability of the turbine. He writes to his partner, Boulton, in 1784: "The whole success of the machine depends on the possibility of prodigious velocities. In short, without God makes it possible for things to move them one thousand feet per second, it can not do us much harm." The advance in tools of precision, and a clearer knowledge of the dynamics of rotating bodies, have now made the speeds mentioned by Watt feasible, and, indeed, common, everyday practise.

Turbines. The turbine of to-day carries the expansion of steam much further than has been found possible in any reciprocating engine, and owing to this property it

has surpassed it in the economy of coal, and it realizes to the fullest extent Watt's ideal of the expansion of steam from the boiler to the lowest vapor pressure obtainable in the condenser.

Among the minor improvements which in recent years have conduced to a higher efficiency in turbines are the more accurate curvature of the blades to avoid eddy losses in the steam, the raising of the peripheral velocities of the blades to nearly the velocity of the steam impinging upon them, and details of construction to reduce leakages to a minimum. In turbines of 20,000–30,000 h. p., 82 per cent. of the available energy in the steam is now obtainable as break-horse-power; and with a boiler efficiency of 85 per cent. the thermodynamic efficiency from the fuel to the electrical output of the alternator has reached 23 per cent., and shortly may reach 28 per cent., a result rivalling the efficiency of internal-combustion engines worked by producer-gas.

During the twenty years immediately preceding the war turbo-generators had increased in size from 500 kilowatts to 25,000 kilowatts, and the consumption of steam had fallen from 17 pound per kw.-hour to 10.3 pound per kw.-hour. Turbines have become the recognized means of generating electricity from steam on a large scale, although they have not superseded the Watt engine for pumping mines or the drawing of coal, except in so far as it is a means for generating electricity for these purposes. In the same period the engine-power in the mercantile marine had risen from 3,900 of the *King Edward* to 75,000 of the *Mauretania.*

As regards the Royal Navy, the engine-power of battleships prior to the war had increased from 12,000 i.h.p., to 30,000 s.h.p., while the speed advanced from 17 knots to 23 knots, and during the war, in ships of the *Queen Elizabeth* class, the power amounted to 75,000 s.h.p., with a speed of 25 knots. In cruisers similar advances were made. The i.h.p. of the *Powerful* was 25,000, while the s.h.p. of the *Queen Mary* was 78,000, with a speed of 28 knots. During the war the power obtained with geared turbines in the *Courageous* class was 100,000 s.h.p., with a speed of 32 knots, the maximum power transmitted through one gear-wheel being 25,000 h.p., and through one pinion 15,500 h.p.; while in destroyers speeds up to 39 knots have been obtained. The aggregate horse-power of war and mercantile turbined vessels throughout the world is now about 35,000,000.

These advances in power and speed have been made possible mainly by the successive increase in economy and diminution of weight derived from the replacement of reciprocating engines by turbines direct-coupled to the propellers, and later by the introduction of reduction gearing between the turbines and the propellers; also by the adoption of water-tube boilers and of oil-fuel. With these advances the names of Lord Fisher, Sir William White, and Sir Henry Oram will always be associated.

The Work of Sir William White.—With the great work of the Royal Navy fresh in our minds, we can not but recall the prominent part taken by the late Sir William White in its construction. His sudden death, when president-elect for 1913, lost to the nation and to the association the services of a great naval architect who possessed remarkable powers of prevision and dialectic. He was Chief Constructor to the Admiralty from 1885 to 1901, and largely to him was due the efficiency of our vessels in the great war.

White often referred to the work of Brunel as the designer of the *Great Eastern,* and spoke of him as the originator of the cellular construction of the bottoms of ships, since universally adopted, as a means of strengthening the hull and for ob-

taining additional safety in case of damage. Scott Russell was the builder of this great pioneer vessel, the forerunner of the Atlantic liners, and the British Association may rightly feel satisfaction in having aided him when a young man by pecuniary grants to develop his researches into the design and construction of ships and the wave-line form of hull which he originated, a form of special importance in paddle-wheel vessels.

So much discussion has taken place in the last four years as to the best construction of ship to resist torpedo attacks that it is interesting to recall briefly at the present time what was said by White in his Cantor lectures to the Royal Society of Arts in 1906:

Great attention has been bestowed upon means of defence against underwater torpedo attacks. From the first introduction of torpedoes it was recognized that extreme watertight subdivision in the interior of warships would be the most important means of defence. Experiments have been made with triple watertight skins forming double cellular sides, the compartments nearest the outer bottom being filled, in some cases, with water, coal, cellulose, or other materials. Armor-plating has been used both on the outer bottom and on inner skins.

He also alludes to several Russian ships which were torpedoed by the Japanese, and he concludes by saying:

"Up to date the balance of opinion has favored minute watertight subdivisions and comparatively thin water-tight compartments, rather than the use of internal armor, the use of which, of course, involves large expenditure of weight and cost."

The present war has most amply confirmed his views and conclusions, then so lucidly and concisely expressed.

While on the subject of steamships, it may perhaps be opportune to say one word as to their further development. The size of ships had been steadily increasing up to the time of the war, resulting in a reduction of power required to propel them per ton of displacement. On the other hand, thanks to their greater size and more economical machinery, speeds have been increased when the traffic has justified the greater cost. The limiting factor to further increase in size is the depth of water in the harbors. With this restriction removed there is no obstacle to building ships up to 1,000 feet in length or more, provided the volume and character of the traffic are such as to justify the capital outlay.

Tungsten Steel.—Among other important pre-war developments that have had a direct bearing upon the war, mention should be made of the discovery and extensive use of alloys of steel. The wonderful properties conferred upon steel by the addition of tungsten were discovered by Muschet in 1868, who has not been sufficiently credited with his share in making the Bessemer process a practical success, and later this alloy was investigated and improved by Maunsel White and Taylor, of Philadelphia. The later showed that the addition of tungsten to steel has the following effect: That after the steel has been quenched at a very high temperature near its melting point, it can be raised to a much higher temperature than is possible with ordinary carbon tool-steel without losing its hardness and power of cutting metal. In other words, it holds the carbon more tenaciously in the hardened state, and hence tungsten-steel tools, even when red-hot, can cut ordinary mild steel. It has revolutionized the design of machine tools, and has increased the output on heavy munition work by 100 per cent., and in ordinary engineering by 50 per cent.

The alloys of steel and manganese with which Sir Robert Hadfield's name is associated have proved of utility in immensely increasing the durability of railway and tramway points and crossings, and for the hard teeth of machinery for the crushing of stone and other materials, and, in fact, for

any purposes where great hardness and strength are essential.

Investigation of Gaseous Explosions.—Brief reference must also be made—and it will be gratifying to do so—to the important work of one of the committees of the British Association appointed in 1908, under the chairmanship of the late Sir William Preece, for the investigation of gaseous explosions, with special reference to temperature. The investigations of the committee are contained in seven yearly reports up to 1914. Of the very important work of the committee I wish to refer to one investigation in particular, which has proved to be a guiding star to the designers and manufacturers of internal-combustion engines in this country. The members of the committee more directly associated with this particular investigation were Sir Dugald Clerk, Professor Callendar, and the late Professor Bertram Hopkinson.

The investigation showed that the intensity of the heat radiated by the incandescent gases to the walls of the cylinder of a gas-engine increases with the size of the cylinder, the actual rate of this increase being approximately proportional to the square root of the depth of the radiating incandescent gas; the intensity was also shown to increase rapidly with the richness of the gas. It suffices now to say that the heat in a large cylinder with a rich explosive mixture is so intense that the metal eventually cracks. The investigation shows why this occurs, and by doing so has saved enormous sums to the makers of gas- and oil-engines in this country, and has led them to avoid the large cylinder, so common in Germany before the war, in favor of a multiplicity of smaller cylinders.

Charles A. Parsons

(*To be continued*)

A QUESTION CONCERNING THE NATURE OF VELOCITY

Tolman's remarkable success in deriving by means of his principle of similitude[1] a large number of physical laws, laws which have also been otherwise derived by the more natural and usual method of experimentation and measurement, ought to indicate that there is probably something fundamentally right about his method of procedure. His argument involves two universes, while physics knows only one—and the bearing of his conclusions upon the single universe that we know is not altogether apparent. When he further asks it to be assumed that the velocity of light and the charge of the electron shall be the same in both universes, his argument seems far removed from the facts of the laboratory and its relevance to the usual physics may be, and indeed has been, brought into serious question.

But his argument may be developed without any appeal to two universes. So developed it has an important bearing upon the theories of the nature of electricity and of the manner of the propagation of light. Consider any two observers in our present universe, each of whom with a different set of standards of measurement makes experiments and determines laws. The laws determined by the two observers will have the same algebraic form and will differ only in the value of the constants which they involve. Since all of the measureable quantities of physics are defined in terms of three fundamental and ultimately undefined quantities, each observer will need only three standards[2] in order that he may

[1] Tolman, *Phys. Rev.*, 3, 244, 1914; 4, 145, 1914; 6, 219, 1915; 8, 8, 1916; 9, 237, 1917. Buckingham, *ibid.*, 4, 345, 1914. Nordstrom, *Finska Vetenskaps Soc. Forh.*, 57, 1914–15; Afd. A. No. 22. Ishiwara, *Science Report of Tohoku Imp. Univ.*, 5, 33, 1916. Ehrenfest-Afanassjewa, *Phys. Rev.*, 8, 1, 1916. Bridgman, *ibid.*, 8, 423, 1916. Karrer, *ibid.*, 9, 290, 1917.

[2] All seem agreed 'that length and time are fundamental and undefinable. About the third quantity, force or mass, or energy, as the case may be, there seems to be considerable debate. The argument of the present paper is valid, whichever one of them is favored. I have chosen *force* be-